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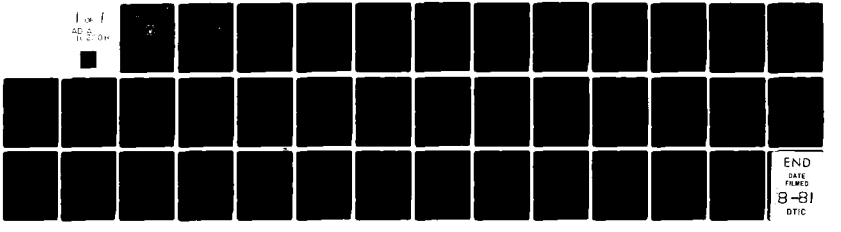

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NAVAL POSTGRADUATE SCHOOL

Monterey, California

A LONGITUDINAL STUDY OF COMPUTER VOICE RECOGNITION PERFORMANCE AND VOCABULARY SIZE

by

Gary K. Poock

June 1981

Prepared for:

Naval Electronic Systems Command
Washington, D.C. 20360

NAVAL POSTGRADUATE SCHOOL

MONTEREY, CALIFORNIA

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This investigation was sponsored by Mr. Frank Deckelman, NAVELEX, Code 330. The work was performed by the author at the Naval Postgraduate School, Monterey, California.

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This research examined voice recognition performance as a function of time and showed no decrement in performance after 21 weeks. In addition, vocabulary sizes up to 240 utterances showed stable performance. Two people also combined their voice reference patterns and were then able to achieve an error rate of less than 2% when either person spoke to the speaker-dependent voice recognition unit.

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FOREWARD

This investigation was sponsored by Mr. Frank Deckelman, NAVELEX, Code 330. The work was performed by the author at the Naval Postgraduate School, Monterey, California.

This report is one of a series concerned with the possible applications of using voice recognition technology in command and control tasks.

I am indebted to the following individuals for their patience and cooperation in working with me for over 5 months on this project: Captain John Armstrong, Canadian Armed Forces; Lt. Cdr. Pam Batchellor, USN; Lt. Kent Bien, USN; Lt. Col. Paul Bragaw, USAF; Capt. Greg Jay, USAF; Prof. Doug Neil, Naval Postgraduate School; and Lt. Cdr. Ellen Roland, USN.

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I. EXECUTIVE SUMMARY

This paper describes an experiment based on 94,560 voice utterances which examined the stability of voice recognition performance over a period of 21 weeks. The purpose was to determine how consistently the voice reference patterns would work and thus indicate how much re-training might be needed over extended periods of time. Recognition performance as a function of vocabulary size up to 240 utterances was also examined. In addition, a small effort was undertaken to examine recognition performance when 2 people combined their training passes, i.e. if the voice recognition equipment required X training passes for each utterance, how well would the recognizer work if one person provided half of the utterances and another person provided the other half of the utterances?

Eight subjects participated in the experiment in which the voice recognizer was tested by having each subject repeat 480 utterances to the recognizer each week for 21 weeks in a relatively noise free environment.

Voice patterns were not allowed to be retrained or "fine tuned" during the study.

In addition, a male and a female made a joint set of reference patterns with half the training passes for each utterance provided by the female and half by the male.

Longitudinal results showed performance was statistically stable over the 21 weeks with no serious degradation occurring as time elapsed. For the 8 subjects who tested the recognizer against their own voice patterns, the recognition error rate over 21 weeks was 2.07% including both mis-recognitions and rejections. In terms of mis-recognitions only, the error rate was 1.65%. In addition, it should be noted that two people (1 male and 1 female) accounted for 57.37% of these errors.

With respect to vocabulary size, analysis showed no statistical differences in performance when the vocabulary size was 20, 40, 60, 80, 100, 120, 140, 160, 180, 200, 220 or 240 utterances.

The two subjects who combined their voice reference patterns had an average error rate of 1.87% with only 6 rejects in total between them.

This small investigation into the joint reference pattern concept suggests that if two persons are on a job and one is unable to continue, the other person could step in and start using the same voice patterns, even though the recognizer is a speaker dependent system.

In summary, voice recognition performance was:

1) Stable over time.
2) Stable over vocabulary size.
3) Quite good when two people combined their voice reference patterns in a speaker-dependent voice recognition system.

II. INTRODUCTION-OBJECTIVE

This paper describes an experiment whose purpose was to examine voice recognition performance as a function of time and vocabulary size. In addition, a small sample was taken to examine the possible use of joint training patterns by two people. Previous research by others working for this writer is shown in Appendix A. The results of some of these studies suggested voice input was a potential way for improving job performance in various applications. Many of these studies were of a relatively short duration of several weeks and it was intriguing to know if the results would have held up over a longer period of time. Hence this study.

III. SUBJECTS

Six military officers and two civilians participated in the longitudinal study over 21 weeks. Two of the officers were female. All subjects were between 20 and 40 years old. Their experience with voice recognition equipment was limited to about a month's previous experience with voice recognition systems, except for 1 male and 1 female who had a year or more of experience. Military ranks ranged from Lieutenant to Lieutenant Commander in the Navy and Captain to Lieutenant Colonel in the Air Force.

IV. INITIAL TRAINING

The eight subjects individually trained a Threshold Technology, Inc., Model T600 voice recognition system on a vocabulary of 240 utterances. After the vocabulary was trained, each utterance was repeated three times with the vocabulary wide open with no branching or structuring. If the voice recognition system correctly recognized the utterance 2 out of 3 times, the training pattern was considered valid... it was retrained if

it didn't meet this criteria and tested again until successful validation was acquired. The T600 initially requires 10 training passes which seems to provide quite good reference patterns. Less than 2% of the initially trained utterances even needed to be retrained to meet the validation criteria.

Upon successful training, each subject's voice patterns were recorded on individual tape cassettes using the tape recorder of the T600. The training patterns were not allowed to be altered for the next 20 weeks.

In addition, one female and one male (both with the most experience with voice recognition equipment) also trained the recognizer in a joint mode on all 240 utterances in which 5 training passes for each utterance were provided by the female and 5 by the male. The validity of these training passes also had to pass the 2 out of 3 criteria (mentioned earlier) for both the male and female. The joint reference patterns were then recorded on a tape which was not altered for the next 20 weeks.

V. THE VOCABULARY

The vocabulary of 240 utterances is shown on the data sheet in Appendix B. It is divided into groups of 20. Each group of 20 was balanced with two 1 syllable utterances, six 2 syllable utterances, four 3 syllable utterances, four 4 syllable utterances and four utterances of 5 or more syllables. These were selected to attempt to simulate their frequency of use in a command center.

VI. PROCEDURE AND DATA COLLECTED

Each week for 20 weeks, 7 of the subjects were observed and measured on recognition performance as they repeated the 240 utterances twice per the

instructions. In the T600, one can set a given utterance's prompt to null and deactivate that utterance and any beyond it.

Therefore, each week a subject's voice pattern tape was read into the recognizer memory and immediately prompt 20 was set to null so only voice reference patterns ϕ through 19 were active. Then the subject repeated these utterances once and then went through them again. The first 20 utterances were therefore being tested against themselves. Next prompt # 20 was reset and prompt # 40 was set to null so now reference patterns ϕ through 39 were active. Then the subject repeated the second 20 utterances twice, but in this case the second set of 20 utterances were actually being tested against all 40 active voice reference patterns. Then when the third set of 20 utterances were tested, they were actually tested against an active vocabulary of 60. Therefore, the vocabulary was opened up by groups of 20 until the last 20 utterances were being tested against an active vocabulary of 240 reference patterns.

Each subject, except one who could only participate for 8 weeks, provided 480 utterances per week for 21 weeks. All eight subjects therefore contributed a total of 74,400 tests of the recognizer's capability.

In addition, the male and female who had made the joint reference pattern tape did "double" duty by each providing another 480 utterances per week which were tested against the patterns on the tape which had their joint reference patterns.

These two subjects contributed 20,160 utterances in this portion of the experiment.

After 20 weeks, all subjects retrained every utterance which had a misrecognition at any time during the first 20 weeks. After validation criteria were again satisfied, data for the 21st week was collected.

The subjects with the joint tape did likewise. Every utterance which previously had a misrecognition by either the male or female was retrained therefore by both subjects. After validation, data for the 21st week was collected.

All data was collected in a relatively quiet atmosphere typical of normal operations in a command center environment or office.

VII. RESULTS

Results for the longitudinal portion of the research are shown in Figure 1. An analysis of variance on the arcsin transformation of the raw data over each week by each subject is shown in Table 1. Subject 4 was not included in the statistical analysis due to his participating in the study for only 8 weeks. The statistical results of Table 1 showed an expected difference between subjects but no difference in performance by week over the 21 weeks. This is seen by observing the overall average curve (the middle one) in Figure 1 which shows less than a 1.7% variation from week to week over 21 weeks. Although the averages for the males and females are shown in this figure individually, the middle average line is more indicative of the group's performance since the females' line is based on 2 subjects whereas the males' is based on six subjects. The overall variability from week to week was large enough to show no statistical difference in general over the 21 weeks of the study. As can be seen, performance did not get worse and worse over time and thus the initial voice reference patterns provided stable performance for the 21 weeks.

This indicates that large amounts of retraining may not be required over extended periods of time, and that performance can remain consistent.

The reader will recall that after 20 weeks, all utterances which previously had any misrecognitions were retrained. One might have thought

TABLE I

Analysis of Variance on

Subjects over 21 Weeks

Source of Variation	df	MS	F
SUBJECTS	6	.4130	82.60*
WEEKS	20	.0056	1.12 N.S.
RESIDUAL ERROR	120	.0050	
TOTAL	146		

*$p < .01$

N.S. = not significant

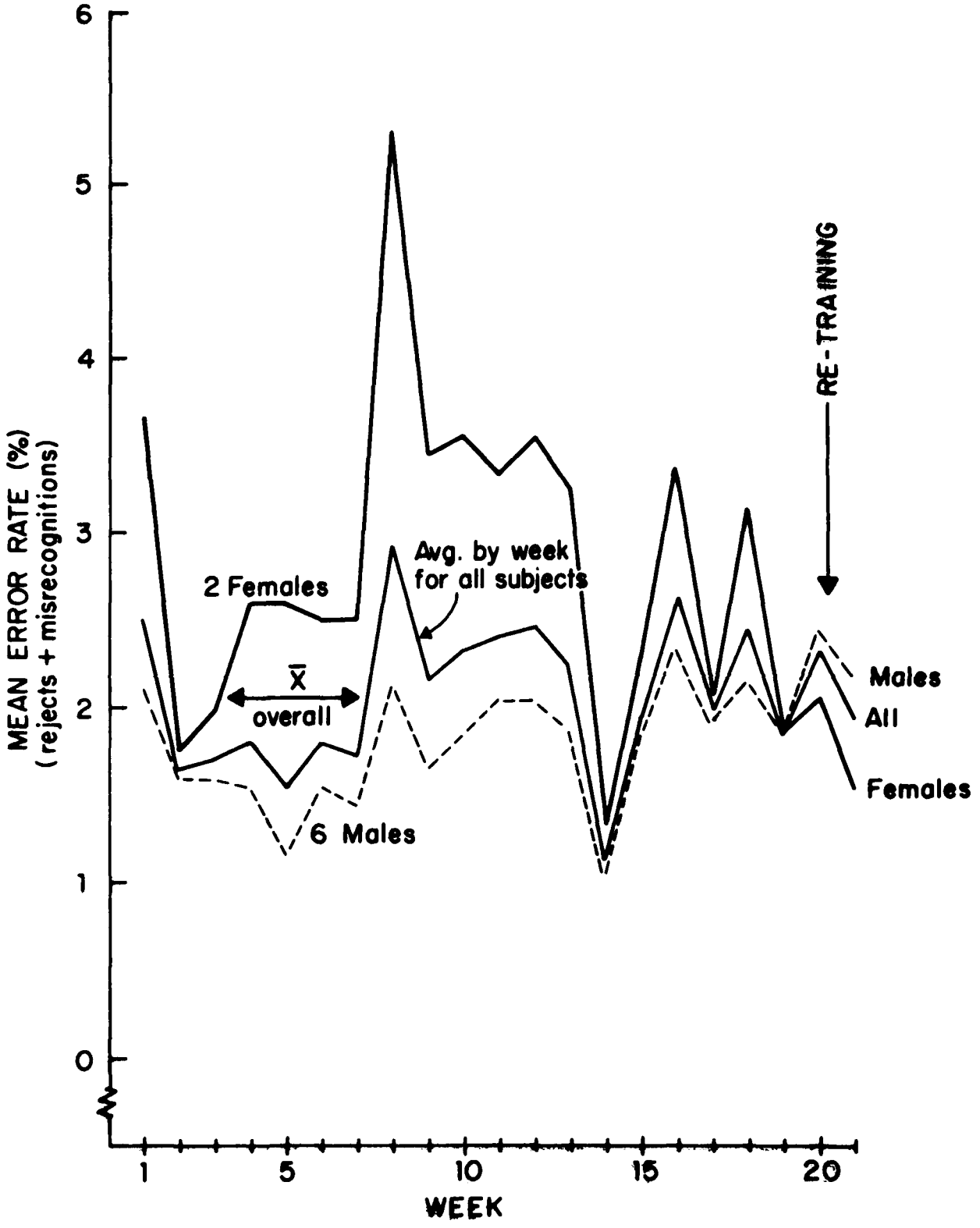

Figure 1: Error rate versus weeks
(individual patterns)

this would help and subsequently cause a large improvement in performance during the 21st week. However, as seen in Figure 1, there was a minimal improvement but nothing statistically significant in the 21st week.

One will notice the average error rate did increase slightly in week 8. This may have no meaning or could be related to exams which would have been given about that time. Also week 14 showed a fair drop in error rate and may have been related to the fact that this was at the beginning of a new academic quarter in which subjects may have been under less pressure. Since these observations are being made after the experiment, one can not take the above implications as true fact. However, it is something to consider and is a small indication of possible stress factors at work. It helps to point out that much remains to be done in the whole area of environmental and psychological stress effects on voice recognition performance.

Figure 2, shows the results of the investigation into vacabulary size.

It can be seen that in general, voice recognition performance remained relatively constant as the size of the vocabulary increased. Statistical analysis showed that the error rate did not increase as a function of vocabulary size as many might expect. Although this writer claims no magic credit for the following, a lot of time was spent developing the vocabulary used here which may be typical of a vocabulary used in command center operations. In addition, each group of 20 utterances was balanced with equal numbers of utterances of 1,2,3,4 and 5 (plus) syllable words. The combination of vocabulary choice and syllable balancing may contribute to performance stability as a function of vocabulary size.

As a result of using different numbers of syllables in the vocabulary, it was also possible to get an indication of how well utterances

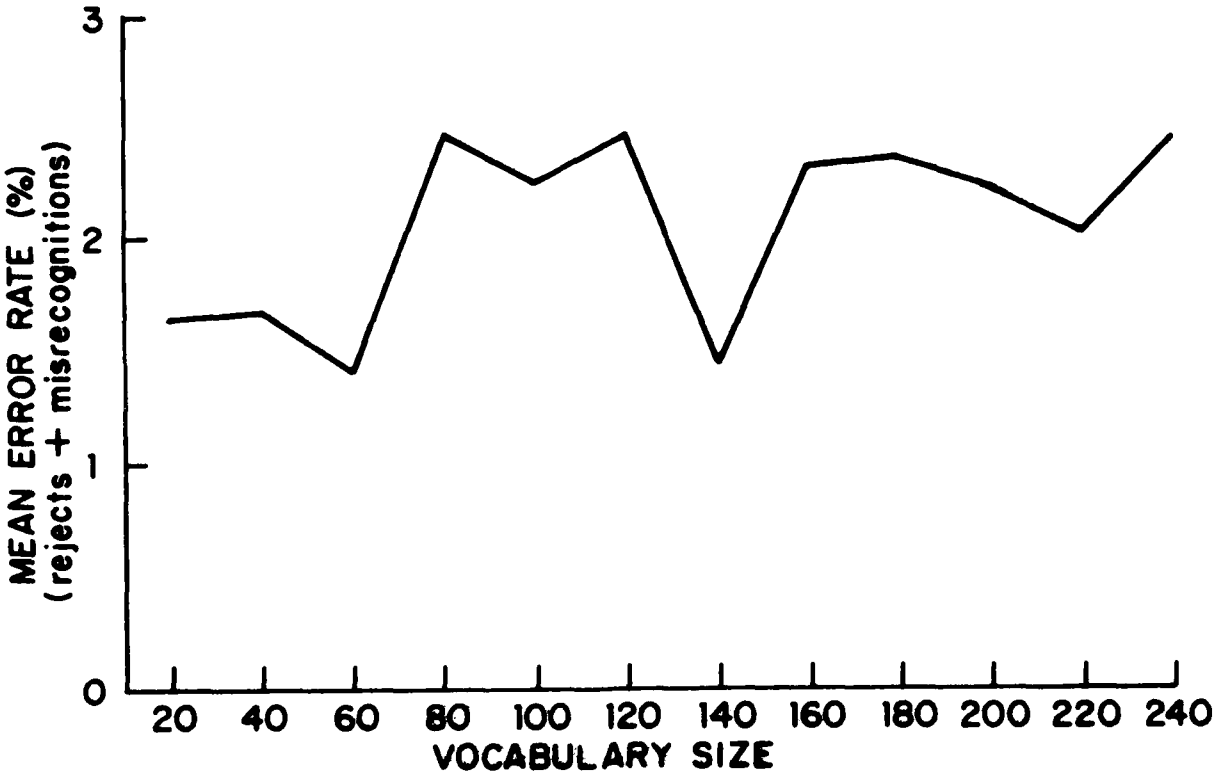

Figure 2: Mean error rate versus vocabulary size.

with different numbers of syllables were recognized. This is shown in Figure 3 which illustrates a declining error rate as a function of the number of syllables in the utterance.

Figure 4 shows the results of the performance for each subject over all 21 weeks. Subjects 1 (male) and 6 (female) were the participants in the joint reference pattern investigation. For both these subjects, their performance dropped about .7% when using the joint patterns versus using their own patterns. It is also interesting to note that subject 1, using joint patterns of female subject 6, performed better than any other subject did against their own individual reference patterns. Subject 4 in this figure is the one who only participated 8 weeks.

Figure 5,6, and 7 simply show the individual subject's error rates by week for the entire study. Subject 1 and 6 in Figure 5 are the same subjects as in Figure 7 but using their individual voice reference patterns versus their combined patterns.

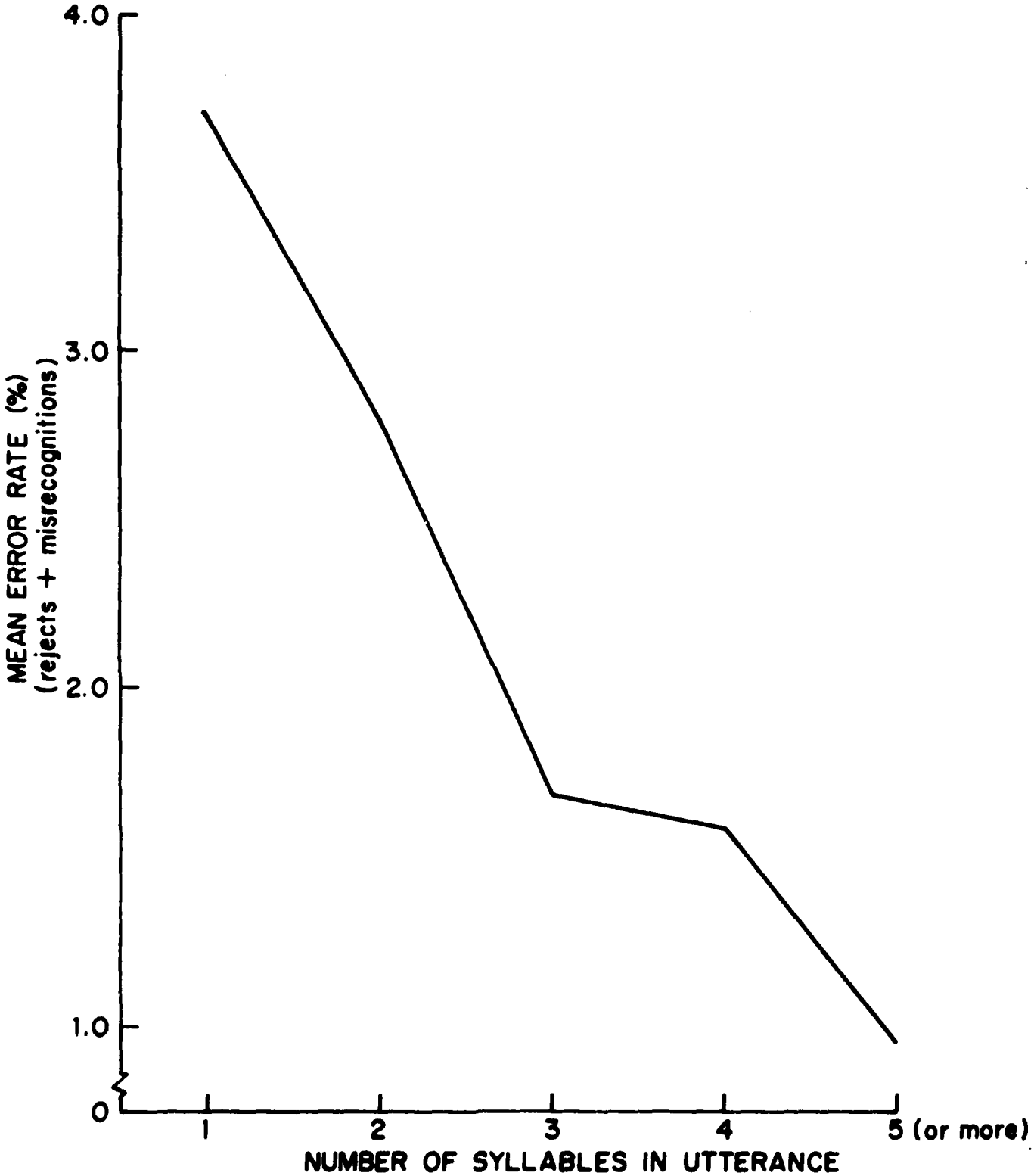

Figure 3: Error rate versus # syllables
(over all conditions)

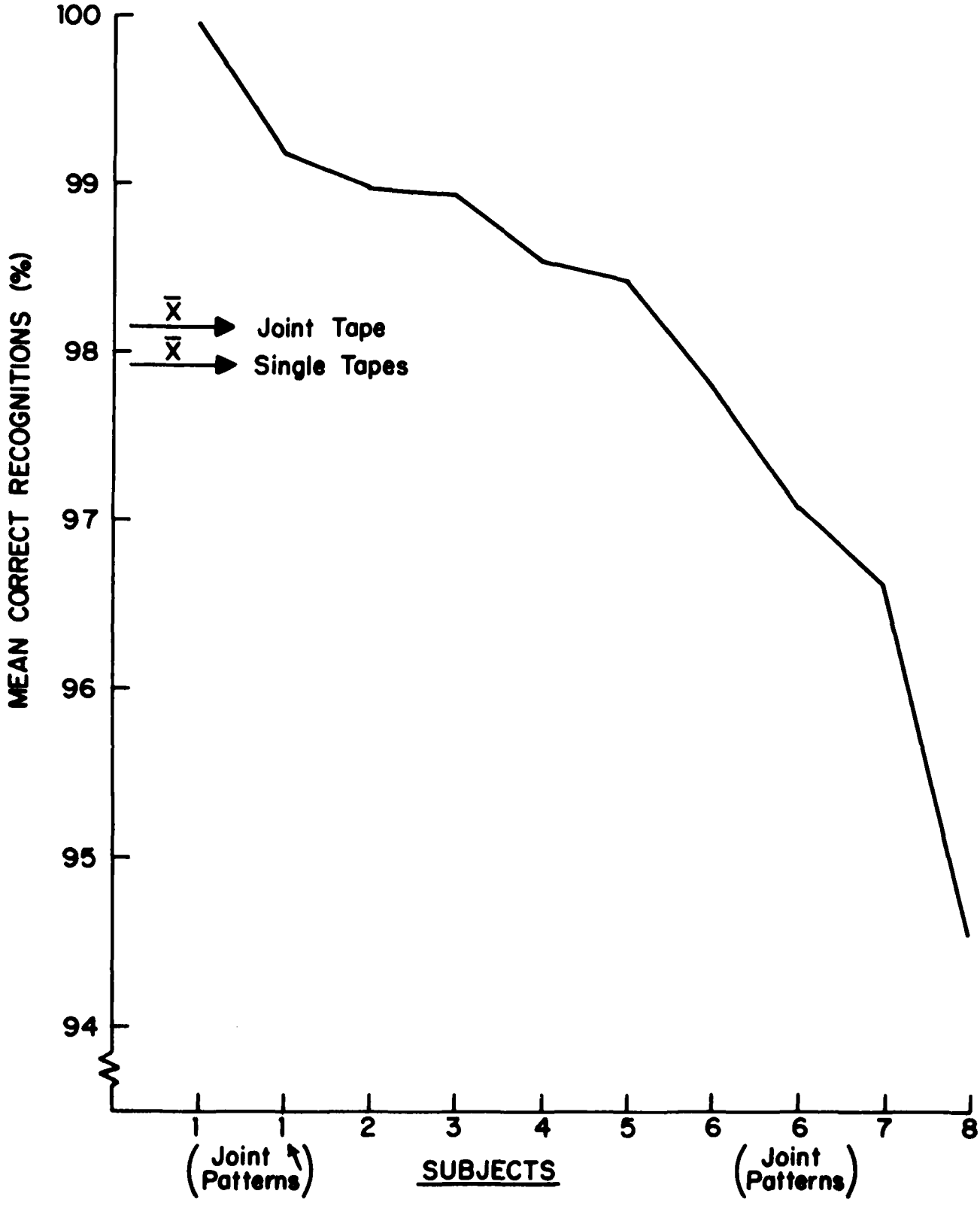

Figure 4: Recognition performance by subject on individual patterns unless noted.

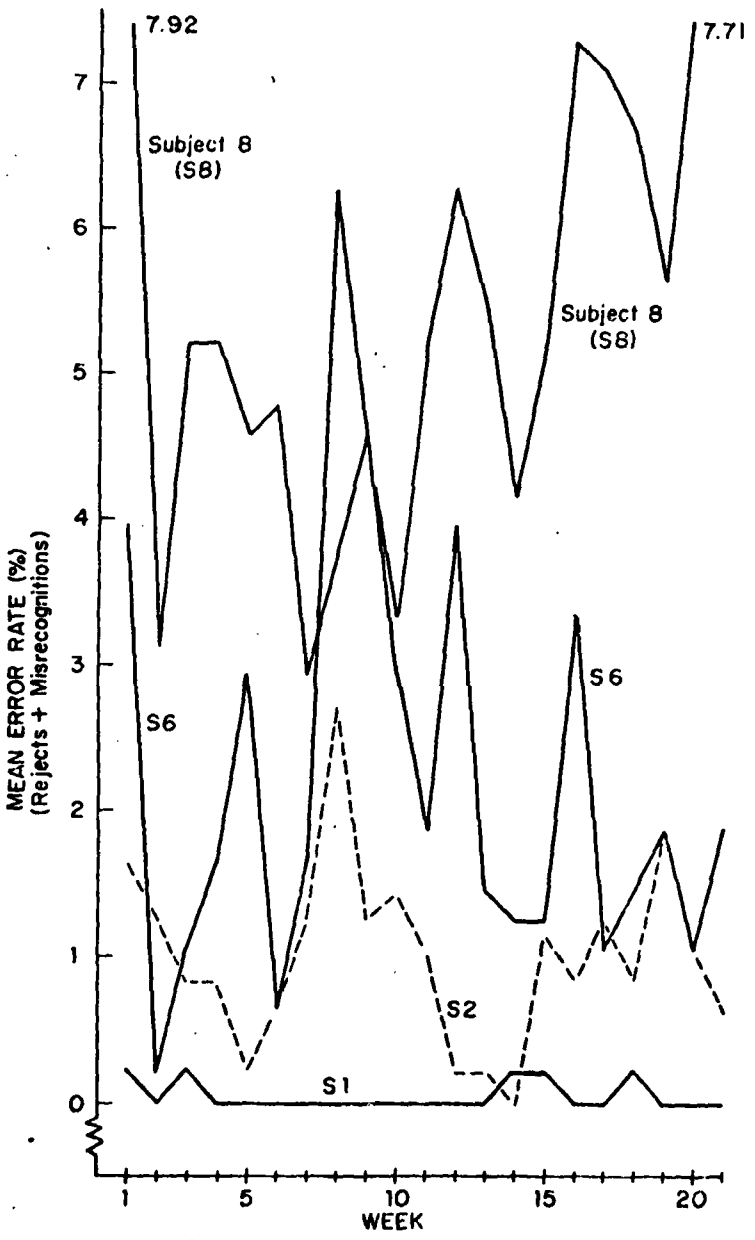

Figure 5: Performance by week for individual subjects (own voice pattern).

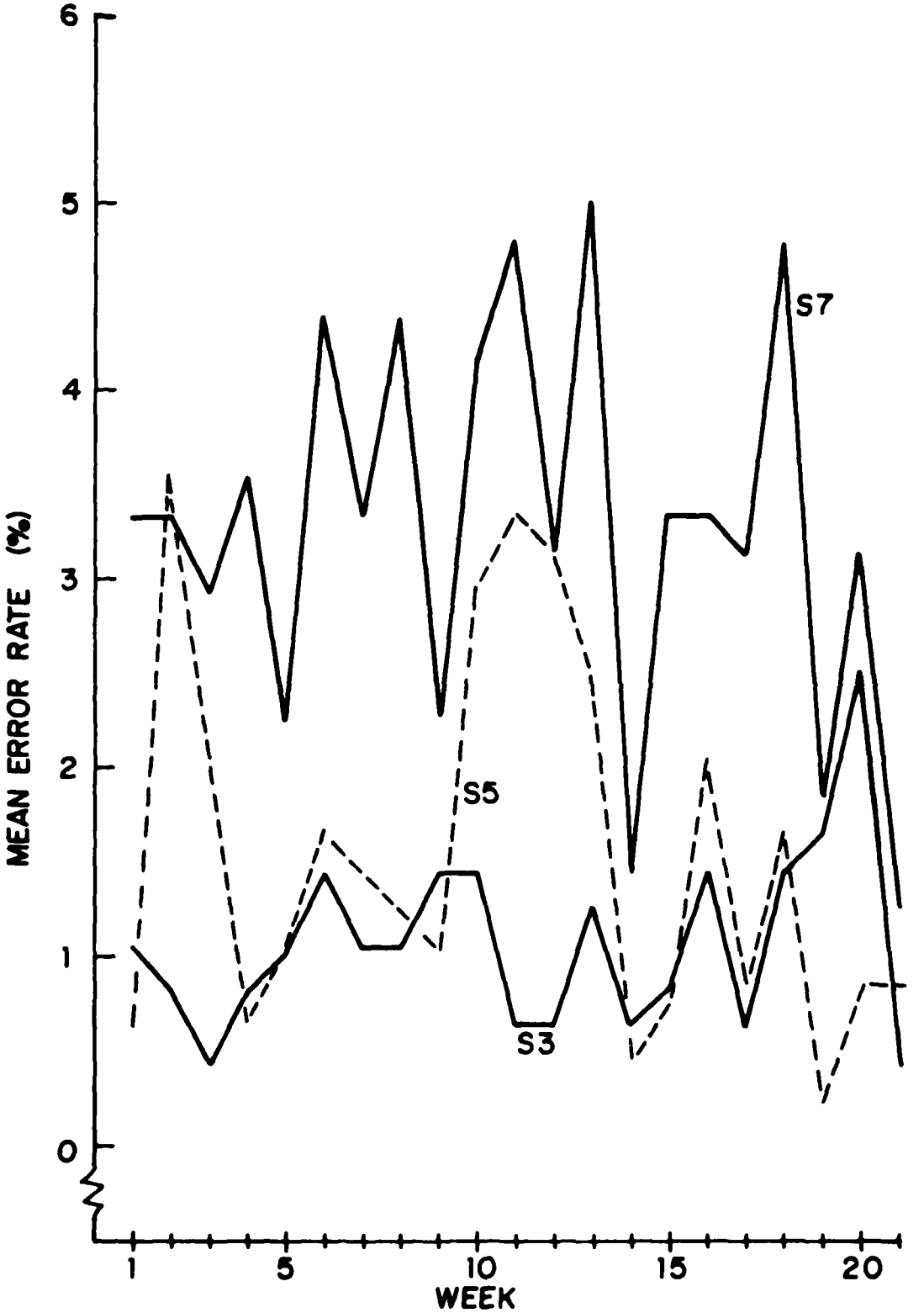

Figure 6: Performance by week for individual subjects (own voice patterns).

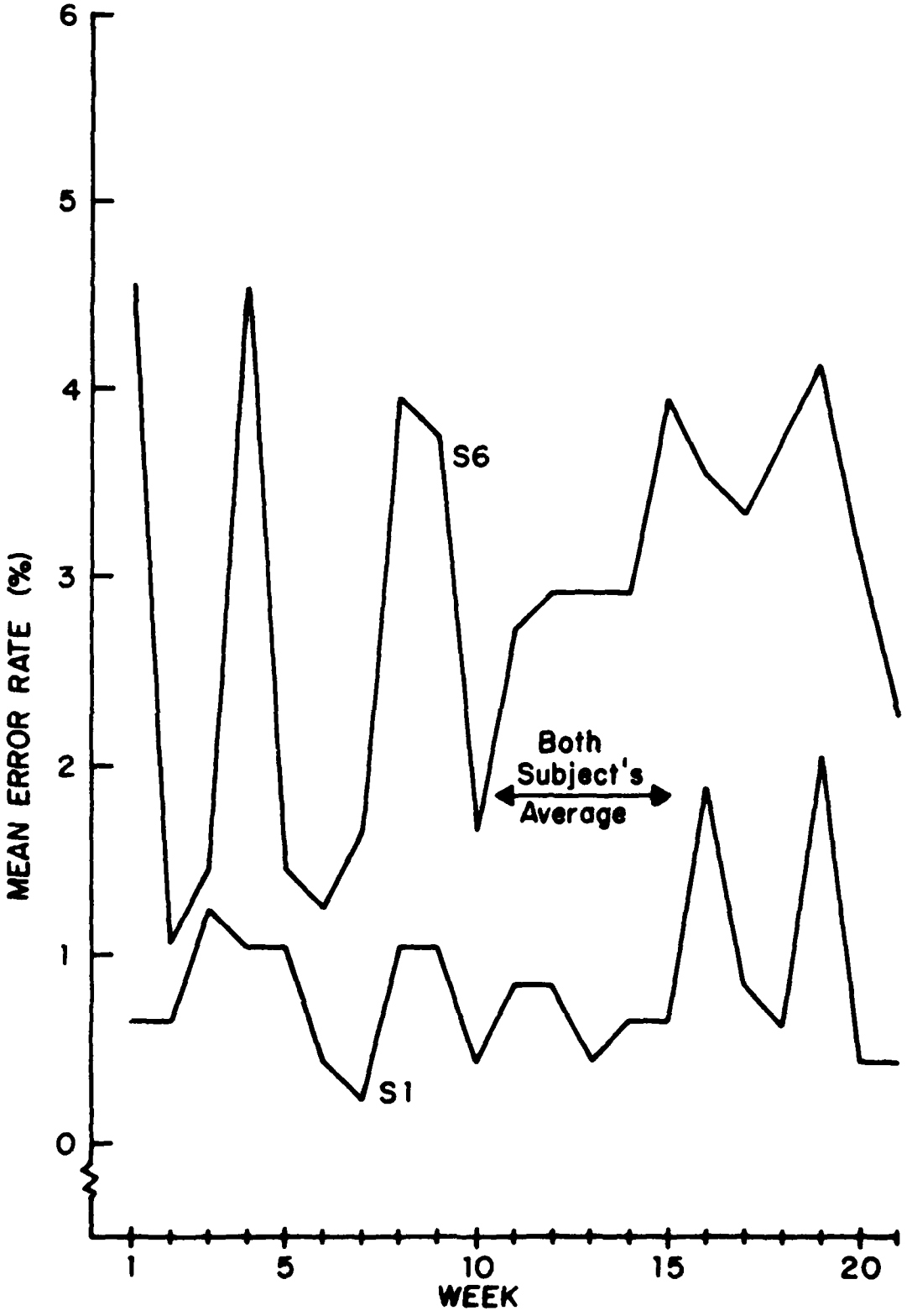

Figure 7: Performance by week for two subjects using combined voice reference patterns.

VIII. CONCLUSIONS

The main purpose of this study was to determine if voice recognition performance could be stable over a "long" period of time. It is apparent that relative stability is possible and one may not have to expect to do a lot of re-training of voice patterns as time progresses over many months. As a matter of record, this writer uses two year old voice reference patterns on a daily basis and hardly ever re-trains any of the old patterns.

As a result of the main experiment, it was also possible to get an idea of recognition performance as a function of vocabulary size. Although one might believe that the error rate should increase dramatically as larger vocabularies are used, the current results indicate that this need not be the case. Rather, it might be argued, one can overcome large vocabulary difficulties through judicious selection of the vocabulary items themselves, as others have suggested in past discussions at conferences, etc.

Finally, it was successfully shown that a male and a remale could combine their voice reference patterns in a speaker-dependent recognition system and still achieve high recognition performance. This has many implications for use in emergency situations where one member of a crew may become incapacitated suddenly. If one didn't wish to have joint patterns for all utterances as done in this study, one might at least have joint patterns for emergency and "STOP-ACTION" types of commands in the vocabulary.

APPENDIX A

VOICE STUDIES AT NPS

This project is one of several voice recognition research projects conducted for/by Professor G. K. Poock at NPS over the last several years. The complete list, in addition to this report, includes:

Armstrong, J. W., The Effects Of Concurrent Motor Tasking On Performance Of A Voice Recognition System, Masters Thesis, Naval Postgraduate School, Monterey, 1980.

Batchellor, M. P., Investigation Of Parameters Affecting Voice Recognition Systems In C^3 Systems, Masters Thesis, Naval Postgraduate School, Monterey, 1981.

Bragaw, P. H., Investigation Of Voice Input For Constructing Joint Chiefs Of Staff Emergency Action Messages, Masters Thesis, Naval Postgraduate School, Monterey, 1981.

Jay, G. T., An Experiment In Voice Data Entry for Imagery Intelligence Reporting, Masters Thesis, Naval Postgraduate School, Monterey, 1981.

McSorley, W. J. Using Voice Recognition Equipment To Run The Warfare Environmental Simulator (WES), Masters Thesis, Naval Postgraduate School, Monterey, 1981.

Naval Postgraduate School Report NPS54-80-010, The Effects Of Certain Background Noises On The Performance Of A Voice Recognition System, by R. Elster, September 1980.

Naval Postgraduate School Report NPS55-80-016, Experiments With Voice Input For Command And Control: Using Voice Input To Operate A Distributed Computer Network, by G. K. Poock, April 1980.

Naval Postgraduate School Report NPS55-81-003, Examination Of Voice Recognition System To Function In A Bilingual Mode, by D. E. Neil and T. Andreason, February 1981.

Taggart, J. L. and Wolfe, C. D., Speech Recognition As An Input Medium For Preflight In The P3C Aircraft, Masters Thesis, Naval Postgraduate School, Monterey, 1981.

APPENDIX B

DATA SHEET NAME _____

LONGITUDINAL STUDY DATE _____

Is this data based on:

- [ ] Your voice patterns?
- [ ] Yours and other's patterns? (Whose?) _____
- [ ] Other's patterns? (Whose?) _____

There are 240 patterns on your tape (word number Ø - 239 in memory).

INSTRUCTIONS:

A. Set the prompt of word 2Ø to a carriage return.

B. Say word 21 to check your vocabulary size (it shouldn't work).

C. Say utterances Ø through 19.

D. Then repeat utterances Ø through 19. We are getting 2 observations per utterance.

E. If the machine beeps, write "BEEP" to the right of the word number.

F. If the machine makes a mistake, write the MISTAKEN output to the right of the word number.

Now go through the list twice on the next page.

WORD #	UTTERANCE
Ø	ONE
1	TWO
2	YANKEE
3	AIR ROUTES
4	GARY POOCK
5	LOAD THE GANN
6	CARRIAGE RETURN
7	LOAD THE SERVER
8	IRAN
9	JAPAN
10	SWEDEN
11	EUROPE
12	LOGIN POOCK
13	LEVEL TWO
14	ACCAT TITLE
15	STRAIT OF HORMUZ
16	LOAD GLD3
17	CONNECT TO CHARLIE
18	POOCK NPS PASSWORD
19	CHANGE DIRECTORY TO HUNTER

Now SET the prompt of word 20 back to "three" and the prompt of word 40 to carriage return. Check vocabulary size by saying word 41. It should not work. Now go through the following list twice.

20	THREE
21	FOUR
22	LOGOUT
23	GRAPHICS
24	RED SPHERE
25	STEAM PLANT
26	ZERO
27	SEVEN
28	NOVEMBER
29	MOVE IT DOWN
30	USE THAT ONE
31	SPIROGRAPH
32	CAPTAIN EBBERT
33	CLOSE OUT CHARLIE
34	UP IN DETAIL
35	UNITED STATES
36	LEVEL TWO VIEWER
37	NORTH ATLANTIC MAP
38	GENISCO ZERO PARAMETERS
39	MEDITERRANEAN MAP

Now set the prompt of word 40 back to "FIVE" and set the prompt of word 60 to carriage return. CHECK vocabulary size by saying word 61. It should not work. Now go through the following list twice.

40	FIVE
41	SIX
42	ALPHA
43	BRAVO
44	CHARLIE
45	DELTA
46	ECHO
47	FOXTROT
48	JULIETT
49	ROMEO
50	MOVE IT LEFT
51	SIERRA
52	SAN FRANCISCO
53	APPLICATION
54	ENGINEERING
55	HUMAN FACTORS
56	VOICE TECHNOLOGY
57	CENTRAL EXPRESSWAY
58	RUSSIAN VERSION OF HORMUZ
59	FILE TRANSFER PROTOCOL

Now Now set the prompt of word 60 back to "EIGHT" and set the prompt of word 80 to carriage return. Check vocabulary size by saying word 81. It should not work. Now go through the following list twice.

60	EIGHT
61	NINE
62	HOTEL
63	INDIA
64	KILO
65	LIMA
66	OSCAR
67	POPPA
68	MOVE IT RIGHT
69	UNIFORM
70	VIETNAM
71	KOREA
72	ADVISORY
73	INTERACTIVE
74	BUSINESS MEETING
75	CONTINUOUS
76	SPEECH RECOGNITION
77	CONTINUOUS SPEECH
78	EFFICIENT TRANSMISSION
79	SYSTEM INTEGRATION

Now set the prompt of word 80 back to "GOLF" and set the prompt of word 100 to carriage return. Check vocabulary size by saying word 101. It should not work. Now go through the following list twice.

80	GOLF
81	MIKE
82	QUEBEC
83	TANGO
84	VICTOR
85	WHISKEY
86	XRAY
87	ZULU
88	MOVE IT UP
89	BANGLADESH
90	TOKYO
91	HOLLISTER
92	DOWN IN DETAIL
93	CORPORATION
94	CRITERIA
95	ADVANTAGES
96	SUITABILITY
97	RADIOLOGY
98	IDENTIFICATION
99	AUTOMATIC RECOGNITION

Now set the prompt or word 100 back to "COURSE" and set the prompt of word 120 to carriage return. Check vocabulary size by saying word 121. It should not work. Now go through the following list twice.

100	COURSE
101	SPEED
102	COMMAND
103	ATTACK
104	BINGO
105	REPORT
106	PROCEED
107	STATION
108	ALTITUDE
109	RECOVER
110	RELOCATE
111	DESIGNATE
112	AVAILABLE
113	PLOT ESM
114	TRACK ENEMY
115	DESIGNATE TRACK
116	COMMAND AND CONTROL
117	PROBABILITY
118	ENEMY DETECTION
119	PROBABILITY OF DETECTION

Now set the prompt of word 120 back to "LAUNCH" and set the prompt of word 140 to carriage return. Check vocabulary size by saying word 141. It should not work. Now go through the following list twice.

120	LAUNCH
121	FIRE
122	CANCEL
123	MESSAGE
124	BEARING
125	LABEL
126	ORDERS
127	COPY
128	SATELLITE
129	ENVELOPE
130	NEGATIVE
131	CORRELATE
132	COMBINATION
133	SENSOR DELAY
134	MANEUVER DELAY
135	ALABAMA
136	TASK FORCE COMMANDER
137	NORTH CAROLINA
138	PROCEED TO NEW DELHI
139	PLACE A CIRCLE ON MOSCOW

Now set the prompt of word 140 back to "TIME" and set the prompt of word 160 to carriage return. Check vocabulary size by saying word 161. It should not work. Now go through the following list twice.

140	TIME
141	SHOOT
142	SURFACE
143	REFUEL
144	MINEFIELD
145	DISTANCE
146	SHORE BASED
147	CONTACT
148	EXECUTE
149	SUBMARINE
150	ENEMY
151	ORDER NAME
152	CONNECTICUT
153	INDIANA
154	OKLAHOMA
155	PENNSYLVANIA
156	CALIFORNIA
157	SOUTH DAKOTA
158	PLACE A MARKER ON PARIS
159	BINGO ALL CRAFT IMMEDIATELY

Now set the prompt of word 160 back to "MAP" and set the prompt of word 180 to carriage return. Check vocabulary size by saying word 181. It should not work. Now go through the following list twice.

160	MAP
161	GRID
162	NEUTRAL
163	MISSILE
164	SENSOR
165	ADAK
166	STOCKTON
167	NEW YORK
168	AIR FIELD NAME
169	TRACK UNKNOWN
170	TRACK FRIENDLY
171	TRACK NEUTRAL
172	BEARING AND DISTANCE
173	LOUISIANA
174	MINNESOTA
175	COLORADO
176	EISENHOWER
177	NEW MEXICO
178	RELOCATE THE SUNFISH
179	REFUEL THE CONNIE

Now set the prompt of word 180 back to "TAKE" and set the prompt of word 200 to carriage return. Check vocabulary size by saying word 201. It should not work. Now go through the following list twice.

180	TAKE
181	PLACE
182	GEORGIA
183	VERMONT
184	TEXAS
185	DANIELS
186	UTAH
187	PLATFORM
188	LATITUDE
189	LONGITUDE
190	OHIO
191	TORPEDO
192	FLIGHT CONTROLLER
193	TRANS WORLD AIRLINES
194	PANGO PANGO
195	KEEP ON STATION
196	LAY A BARRIER
197	GROUND CONTROL APPROACH
198	ATTACK BARRIER TARGET
199	ATLANTIC DATA BASE

Now set the prompt of word 200 back to "SCOPE" and set the prompt of word 220 to carriage return. Check vocabulary size by saying word 221. It should not work. Now go through the following list twice.

200	SCOPE
201	DROP
202	BANGKOK
203	BOMBAY
204	BRISBANE
205	CANTON
206	ANTWERP
207	AFRICA
208	ARKANSAS
209	SAIGON
210	USER'S GUIDE
211	KITTY HAWK
212	ACAPULCO
213	VLADIVOSTOK
214	YOKOHAMA
215	SEA OF JAPAN
216	DIEGO GARCIA
217	INDONESIA
218	PACIFIC DATA BASE
219	ARABIAN TANKER

Now set the prompt of word 220 back to "MAINE" Now go through the following list twice.

220	MAINE
221	SAVE
222	PORTLAND
223	RANGOON
224	ASPRO
225	KIEV
226	RED FOX
227	NAPLES
228	BLUE FORCE ONE
229	CALCUTTA
230	BALTIMORE
231	WYOMING
232	SEVASTOPOL
233	HONOLULU
234	KRENOMETR
235	JOHN KENNEDY
236	PLOT ALL SUBMARINES
237	UNITED AIR LINES
238	IBERIAN CARRIER
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